Advanced Ceramics

Goddard Road
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DOE/IHEA

Process Heating Materials Forum

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Oak Ridge National Laboratory

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Advanced Ceramics

Acknowledgements

- United States Advanced Ceramics Association (USACA)
- Researchers at Saint-Gobain Ceramics & Plastics, Norton Company, Carborundum
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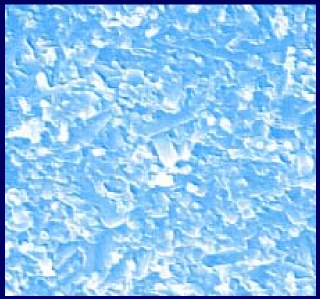
Overview -- Advanced Ceramics

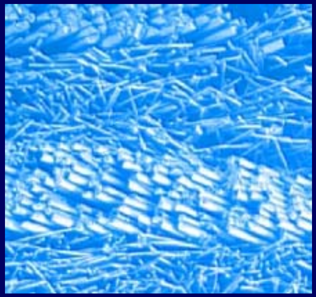
Compositions and Classes (Structural)

- > Monolithic
- > Ceramic Composites (CFCC)
- > Ceramic Coatings



Processing, Reliability, Cost

- > Barriers to Commercialization



Examples of Government Initiatives

Applications and Opportunities Relevant to the Industries of the Future R&D Priorities

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Monolithic Ceramics Composition Emphasis

What is a Monolithic Ceramic?

Oxides

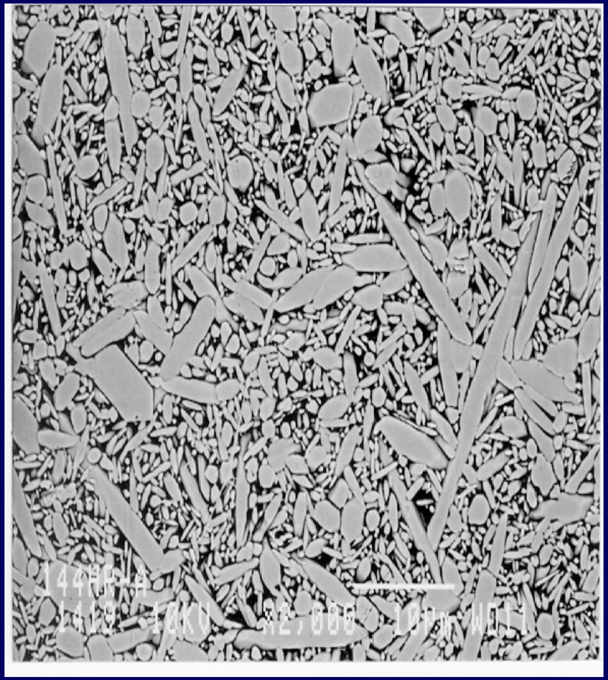
> Alumina, Zirconia (toughened), ZTA, Quartz, AZS…..

Nitrides

> Silicon Nitride, BN,……

Carbides

> Silicon Carbide, B_4C…….



AS800 Silicon Nitride

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Typical Ceramic Processing

In-Process Control

Characterization:
- Powder
- Green Body
- Dense Body
- Machined surface

NDE

Process Control
- SPC

Intelligent Processing

Process	Process Examples
Powder Processing	Milling, Blending Slurry Prep, Spray Drying, Freeze. Granulation, Fusion
Forming	Next Page
Green Machining	CNC, single point tool
Firing	Pressureless Sintering, GPS, HIP, HP
Machining	Diamond Grinding, Lapping, Polishing
Inspection	

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Forming of Monolithic Advanced Ceramics

Dry Forming

- > Uniaxial Pressing, CIP, Dry Bag IP,
- > CNC Green Machining
- > Hot Pressing

Casting

- > Slip Casting, Pressure SC, Freeze Casting

Solid Casting

- > Gel Casting, Starch Casting, Injection Molding, Extrusion, Tape Casting

Rapid Prototyping, Layer Processing

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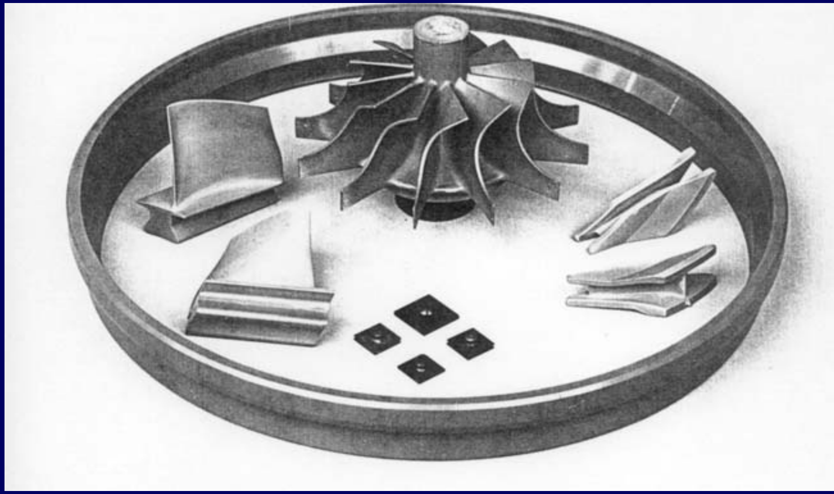
Material and Process Qualification

Viable Process

- > Yield
- > Scalability

Qualification of material properties must be consistent with cost-effective process

- > Properties of large cross section vs. tile
- > Surface properties, reaction layer, environmental resistance
- > As-processed surface vs. machined surface
- > Machining anisotropy



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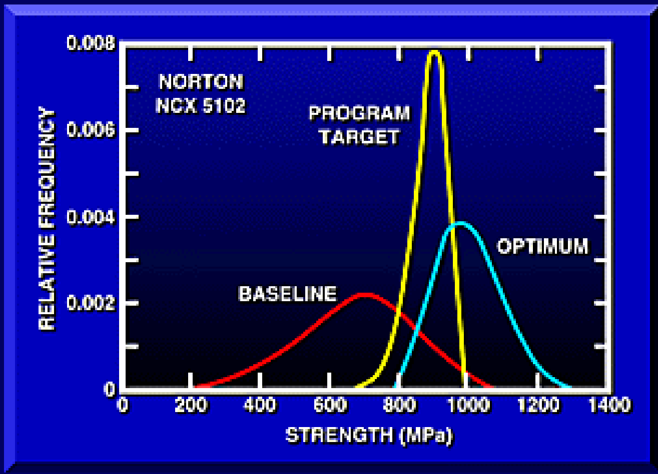
Ceramics R&D for Automotive GT

DoD Ceramics for High Performance -- ‘70s & ‘80s

DOE Auto Gas Turbine, ATTAP

ORNL Ceramic Technology - DOE OTT (1983 Start)



> RELIABILITY
  - Improved Processing - Norton/Saint-Gobain
  - Life Prediction (Allison, AS, Norton/TRW)

> COST-EFFECTIVENESS
  - Norton/DDC ACMT Valves, Innovative Grinding Wheel

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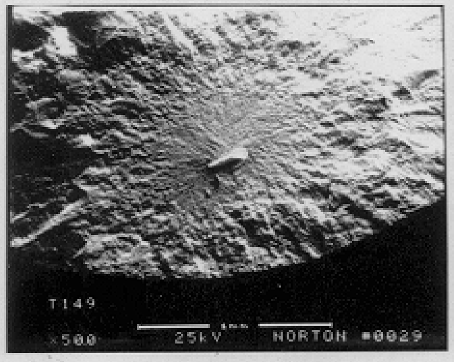
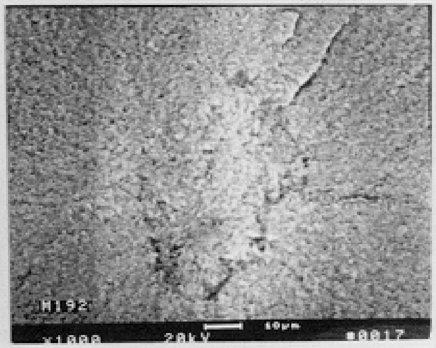
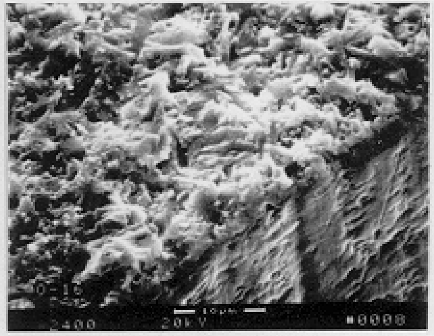
Chronology of Process Improvements for Si_3N_4



Injection molded tensile bar failed at 444 MPa due to 200μm metallic inclusion

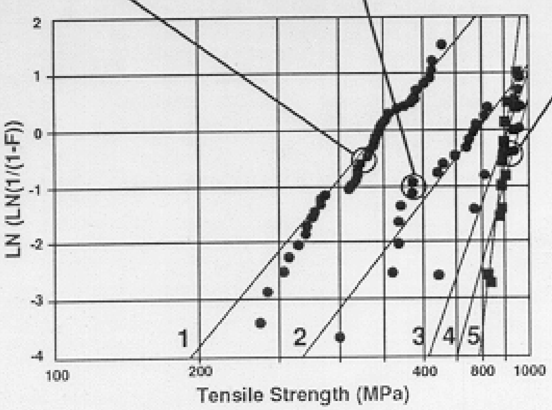


Fracture surface of pressure cast tensile bar which fractured at 570 MPa from 65μm agglomerate



Failure origin at surface of 884 MPa strength tensile bar centered about a 5μm wide machining groove from iteration 4

1. I.M. Baseline: m=4.2
2. P.C. Baseline: m=4.7
3. C-Series only: m=10.1
4. Iteration 3: m=13
5. Iteration 4: m=28



Tensile Strength data illustrating improvements from injection molding baseline iteration (Weibull modulus m=4.2, characteristic strength σ_0=492MPa) to pressure casting iteration 4 (m=28, σ_0=904MPa)

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DOE Industrial Gas Turbine

Advanced Turbine Systems

> Ceramic Composites, Coatings and Monolithics

Advanced Microturbine Systems

> 25 kW to 500 kW (or to 1 MW)

> Goals:

- **Increase efficiency to > 40 %**
- **Enabling technology: Si3N4 ceramics and EBC**
- **Less than 7 ppm NOx**
- **Durability -- 11,000 hours bet major overhaul, 45,000 hour service life**
- **Cost of Power, $500/kW (now ~$1,000)**
- **Fuel Flexible**

Silicon Nitride Bearing Components

~1972 Demonstrate concept/feasibility

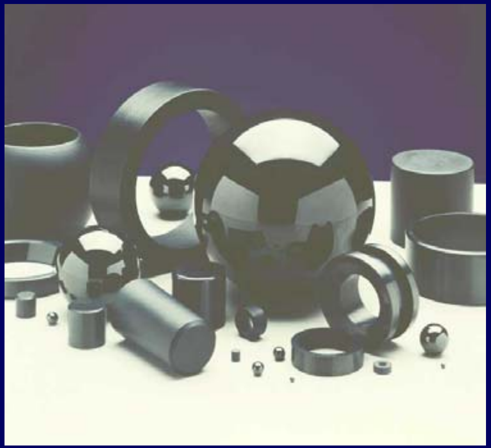
- > Temp & Corrosion Resist, Low Lubricity, Hi Mod, Hi speed, long life, low weight
- > HPSN, DoD interest, NavAir

1984 - 1990 Process for performance and reliability - ASEA HIP Technology

1990-1995 Scaling-up

- > market acceptance (machine tools, then sporting equip, aerospace mainshaft & ball screw, dental, industrial pumps)
- > 3-10 X Life, 80% Lower η, 20% lower E
- > new dedicated facility

1995-2000 Further material developed to reduce processing costs



Need Patience!

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Silicon Carbide

Characteristics

> High hardness, high stiffness/wt, high thermal conductivity, to 1500 C, relatively low toughness vs. Si_3N_4

Typical Properties

Types	Mod (GPa)	MOR (MPa)
> Recrystalized (Crystar)	210	110
> Nitride Bonded (Advancer)	235	180
> Siliconized-ReXL (Crystar)	280	255
> RB, Si-ReXL (NC430)	385	300
> Fine Grain RB (NT230)	395	410
> Sintered Alpha (Hexoloy)	410	459
> HPSC (NC-203)	450	483

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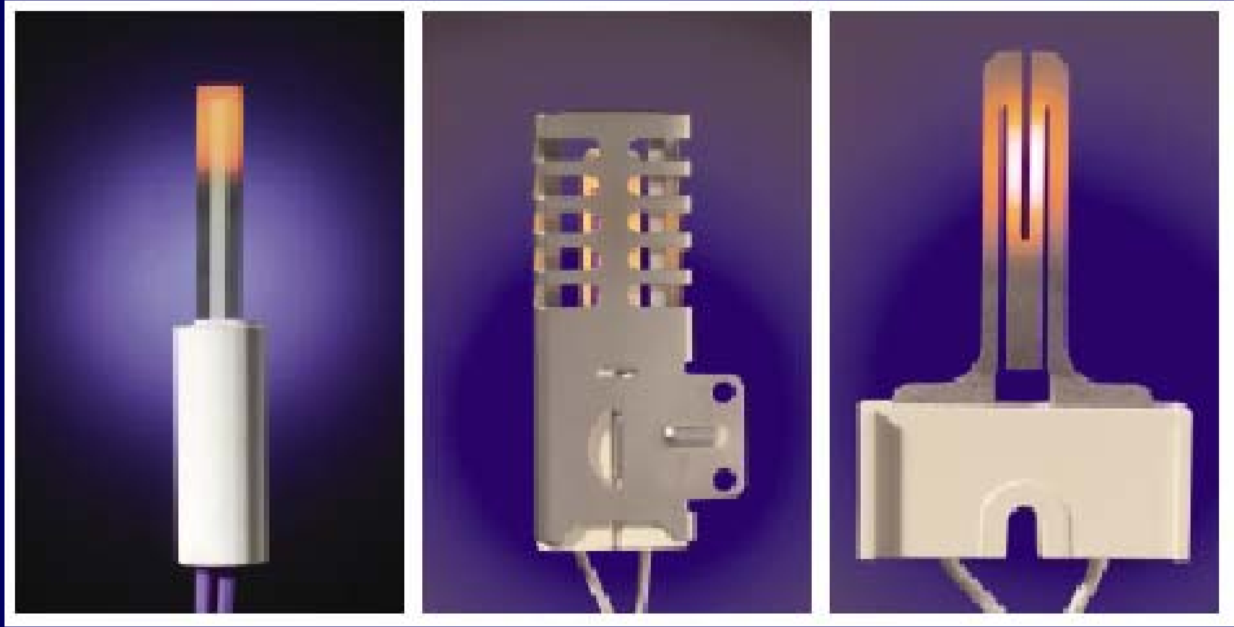
Ceramic Hot Gas Igniters



Pilotless Ingition

Reliablility over Spark Ignition

Energy Savings

Markets

- > Heating
- > Commercial Cooking
- > 12-Volt Equipment
- > Dryer and Range
- > Analytical

Typical/Performance

- > SiC and multi-phase
- > 24 and 120-volt
- > ~1000 to 1500 C and
- > 2 sec to 30 sec

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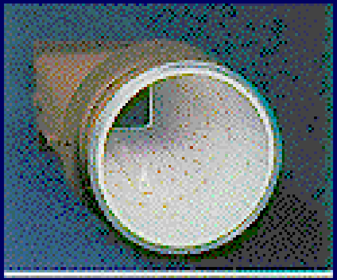
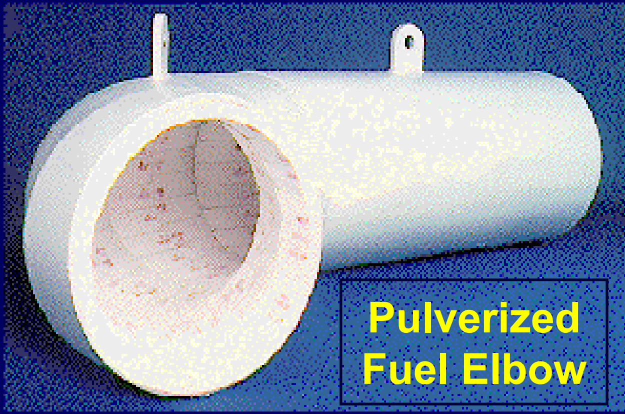
Aluminum Oxide

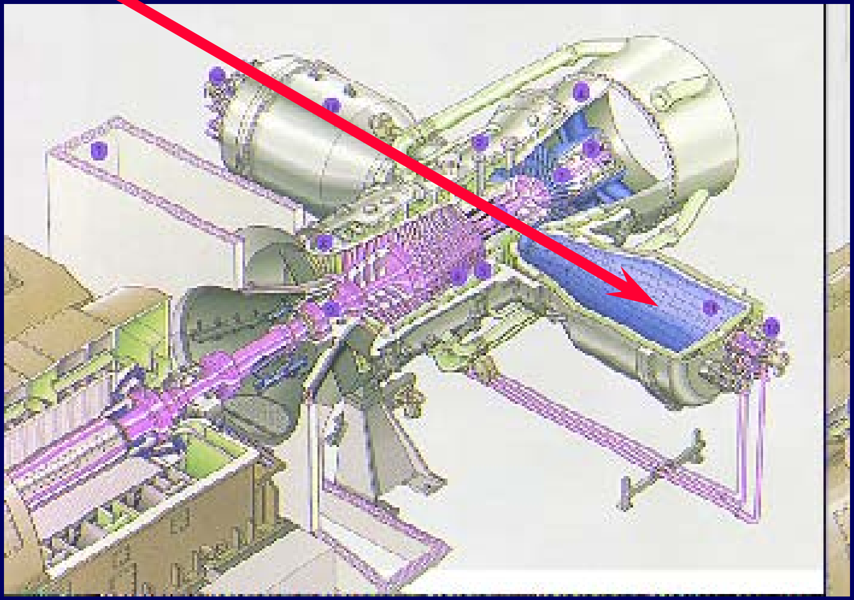
Burner nozzle:
Coal-fired Power Plant





Alumina Tiles

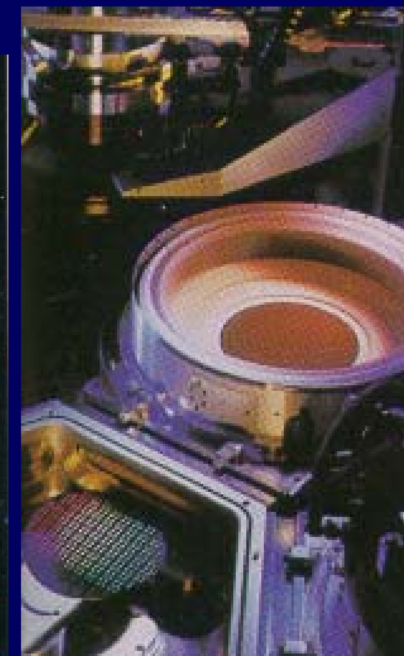
- Siemens Combustor
- Higher combustion temperatures than metals
- Higher engine efficiency & lower emissions than competitors



SiC, Quartz, Al_2O_3, AlN Components for Semiconductor Manufacturing

Quartz

Alumina



Aluminum nitride

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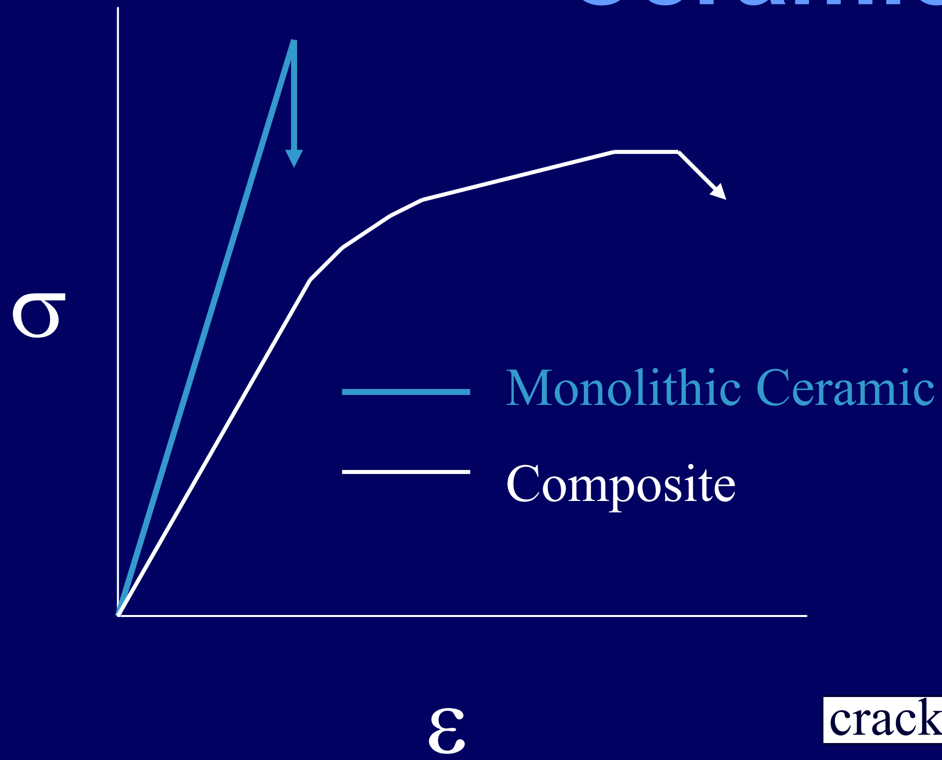
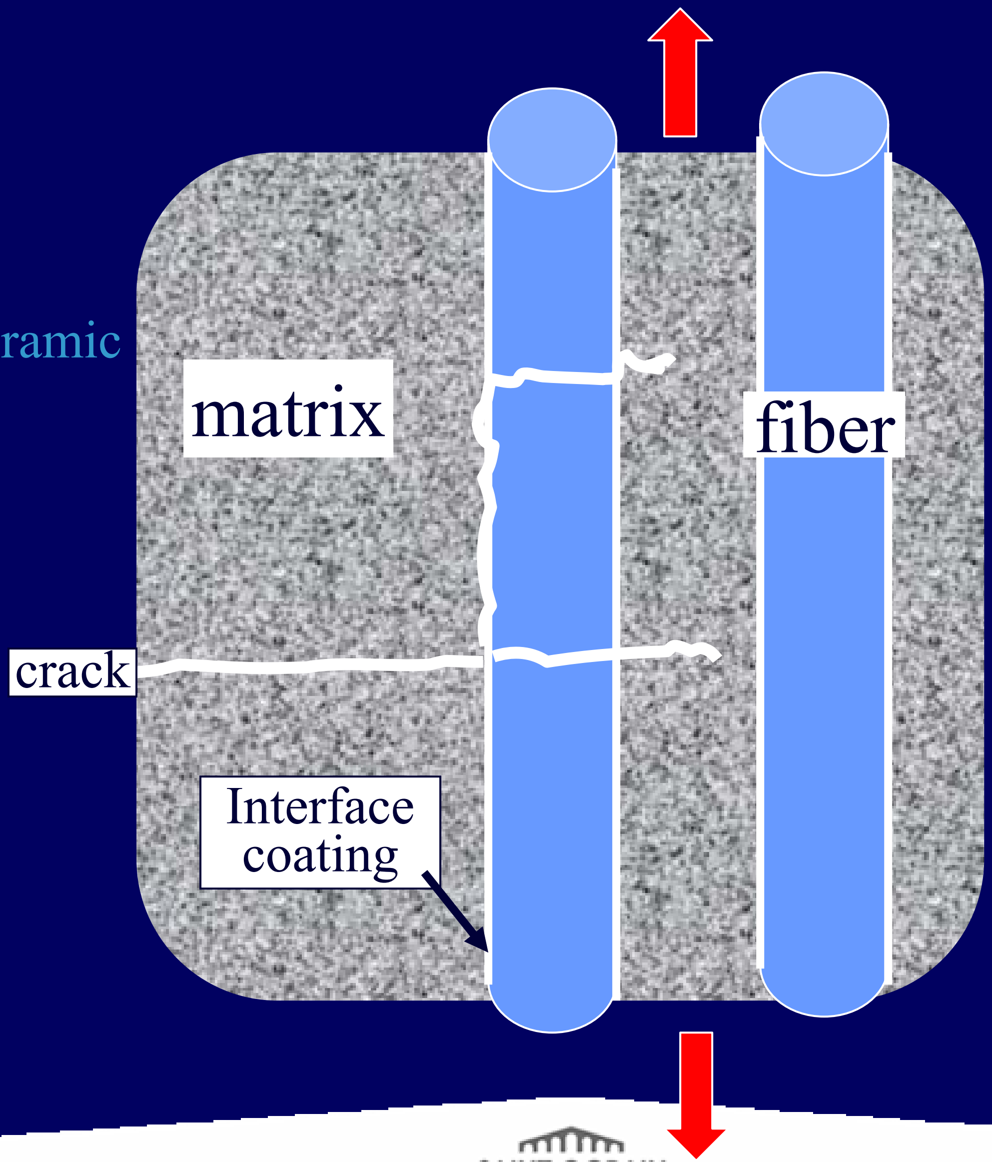
Ceramic Composites





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Ceramic Matrix Composites

PMC Example - Government Funding Model

- > Military/Aerospace Development helped overcome initial manufacturing cost barriers leading to Civil Applications.

DoD and NASA CMC Programs

- > NASA Enabling Propulsion Materials Program Part of National Aerospace Plane (NASP), now part of UEET
- > MI - SiC/SiC composite

DOE/Industry Efforts beyond Military

- > CFCC Program - DOE Industrial Technologies, 1992
  - Industrial Applications - Collaborative effort between industry National Laboratories, universities and government
- > Industrial Gas Turbine Programs

CFCC Examples - Textron

Nitride Bonded SiC matrix reinforced with SiC fibers. Tubes made by filament winding process.

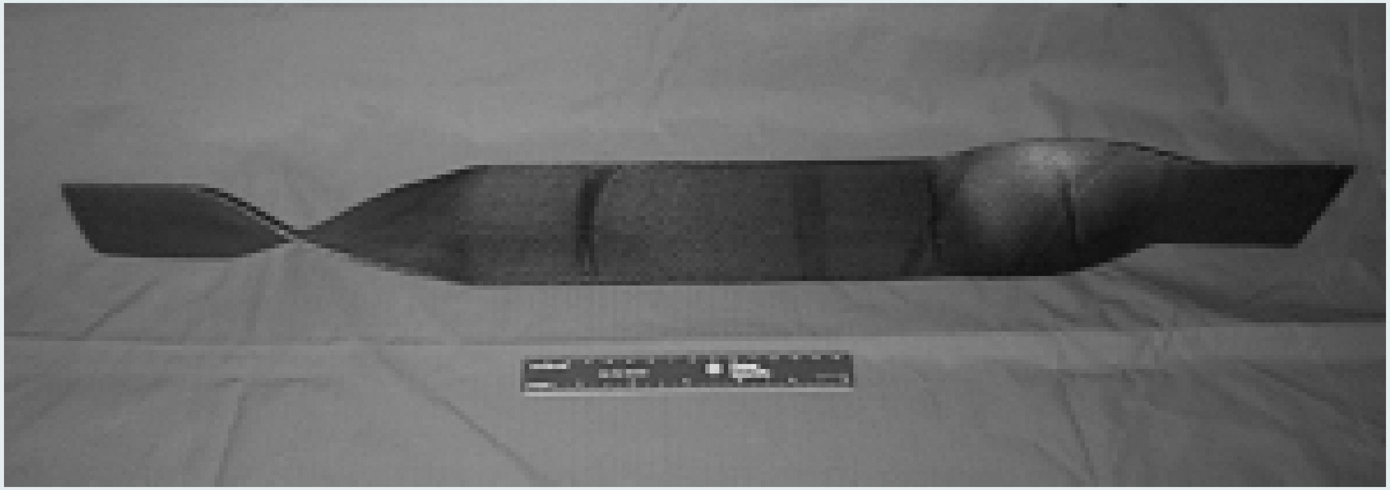
Immersion Tubes

CFCC immersion tubes (36 inches long - shown above entering a melt pot) may be an energy efficient alternative for melting aluminum.

CFCC Examples - Dow Corning

SiC/SiC composites by Polymer Impregnated Pyrolysis (PIP).

FURNACE FAN BLADE



CFCC fan blades (individual blade shown above) help provide operational and energy efficiency advantages in heat treating.

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CFCC Examples - Dow Corning

SiC/SiC composites by Polymer Impregnated Pyrolysis (PIP).

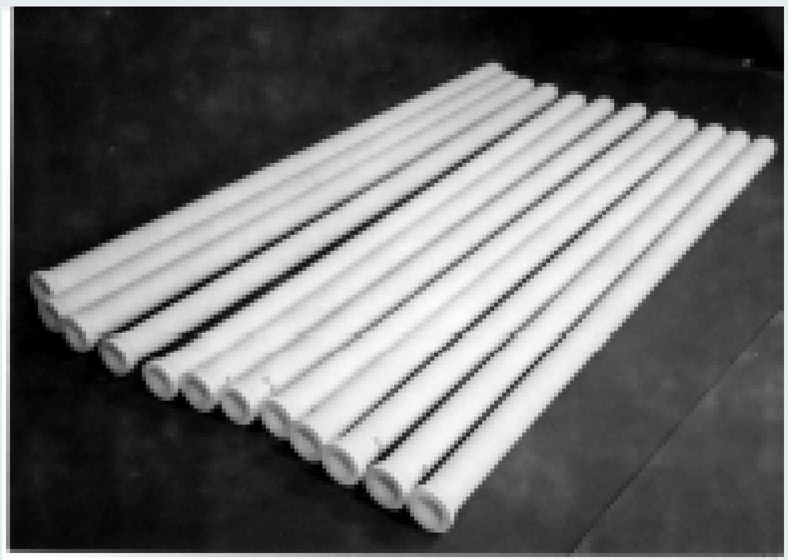
Refinery Pipe Hangers

CFCC tube hangers (shown above - 18 and 39 inches long) can support refinery pipes exposed to temperatures up to 2,200^0 F.

CFCC Examples - McDermott

Oxide-oxide composite, Fiber slurry and sol-gel impregnation process.

HOT GAS CANDLE FILTERS



Individual hot gas filters (left - 1.5 meters long) and filter assembly (right).

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Advanced Turbine Program

Goals: Lowering emissions and improving the performance of industrial gas turbines. Gas turbines in 1MW to 20MW size will play critical role in deployment of Distributed Energy Resources. Builds on success of the Advanced Turbine System Program (ATS), completed in 2001.

4 Advanced Material Awards

GE

- **Teledyne**
- **Siemens Westinghouse**
- **Solar Turbines**

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Industrial GT Materials Portfolio

Ceramic Matrix Composites (CFCC) including Environmental Barrier Coatings

> Compustor Liners, Shrouds

Thermal Barrier Coatings

> Blades, Vanes

Metal Alloys (powder nickel superalloys and titanium silicon carbide)

> Inlet Nozzle, Rotor, Scroll

Oxide dispersion-strengthened alloys

> Compustor Liners, Injector Tips

Monolithic ceramics

> Injector Tips

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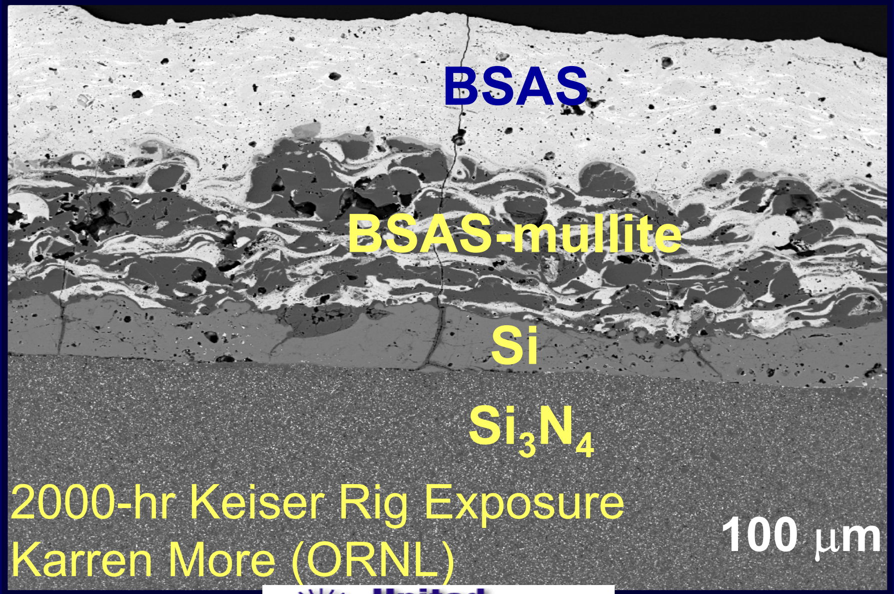
Ceramic Coatings

Metal, Ceramic and CMC Substrates

TBC

EBC

Wear Resistance



United Technologies Research Center

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Ceramic Coating Processes

Plasma Spray Ceramic Powders

> Highest deposition rates (~25 lb/hr). Thicker

High Velocity Oxyfuel (HVOF)

> Powder and binder. Good for cermets

Flame Spray Coating, ROKIDE®

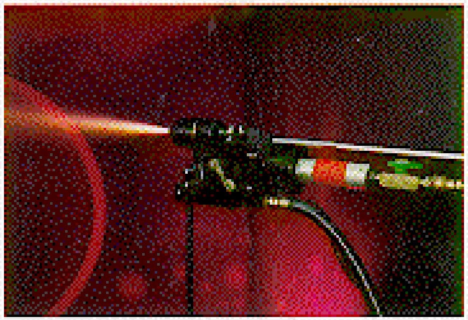
> Ceramic rods are melted, atomized and sprayed at high velocity

> Congruently melted ceramic, More homogenous coating

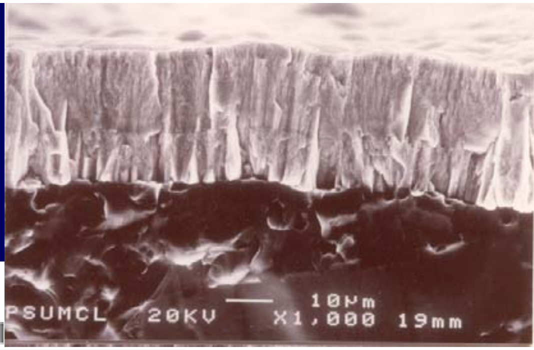
EBPVD

> EB vaporized target. Emerging technology

> Higher rate that PVD/CVD. Collimated microstructure ideal for TBC



Dense Y_2O_3 on SiC by EB-PVD



Thermal Spray Coating - ROKIDE®

Petrochemical/Oil

- > Pumps
  - Sleeves
  - shafts
  - Impellers
  - Casings
- > Mechanical Seals
- > Valve Stems

Aviation/Aerospace

- > Rocket Engine Exhaust Cones
- > Rocket Nozzles
- > Turbine Castings
- > Compressor Castings
- > Rocket Flare Tubes

Paper

- > Pump Sleeves, Impellers and Castings
- > Uhle and Calender Rods
- > Moyno Rotors
- > Refiner Sleeves
- > Jordan Sleeves
- > Claflin Sleeves

Wire

- > Wire Drawing Capstans and Rolls
- > Wire Sheaves
- > Wire Pulleys

Rod compositions

Alumina

Alumina/Zirconia

Alumina/Titania

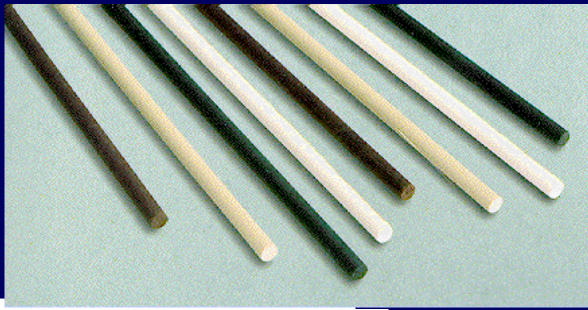
Chrome Oxide

Magnesium Aluminate

Magnesium Zirconate

Zirconia

Zirconium Silicate



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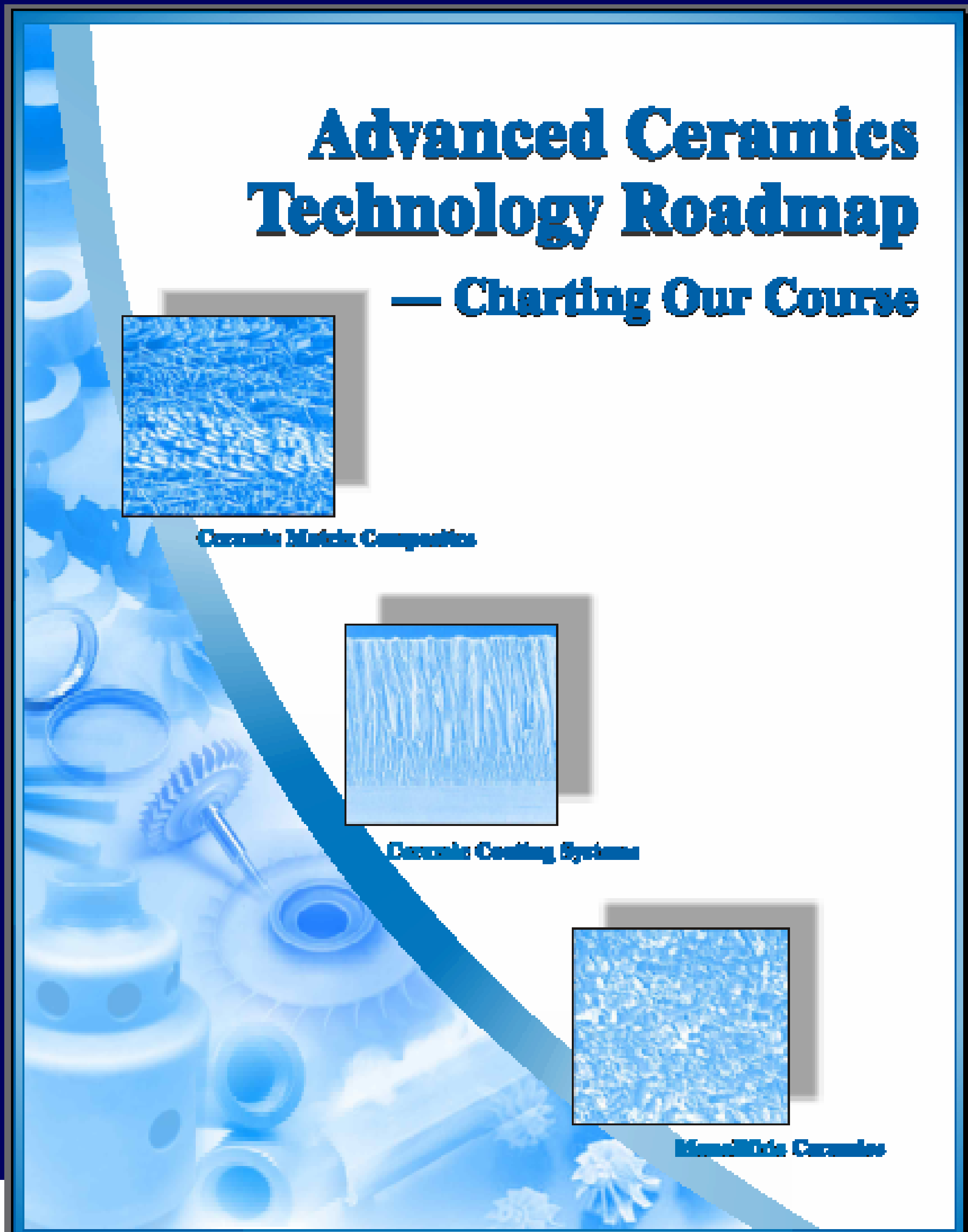

USACA

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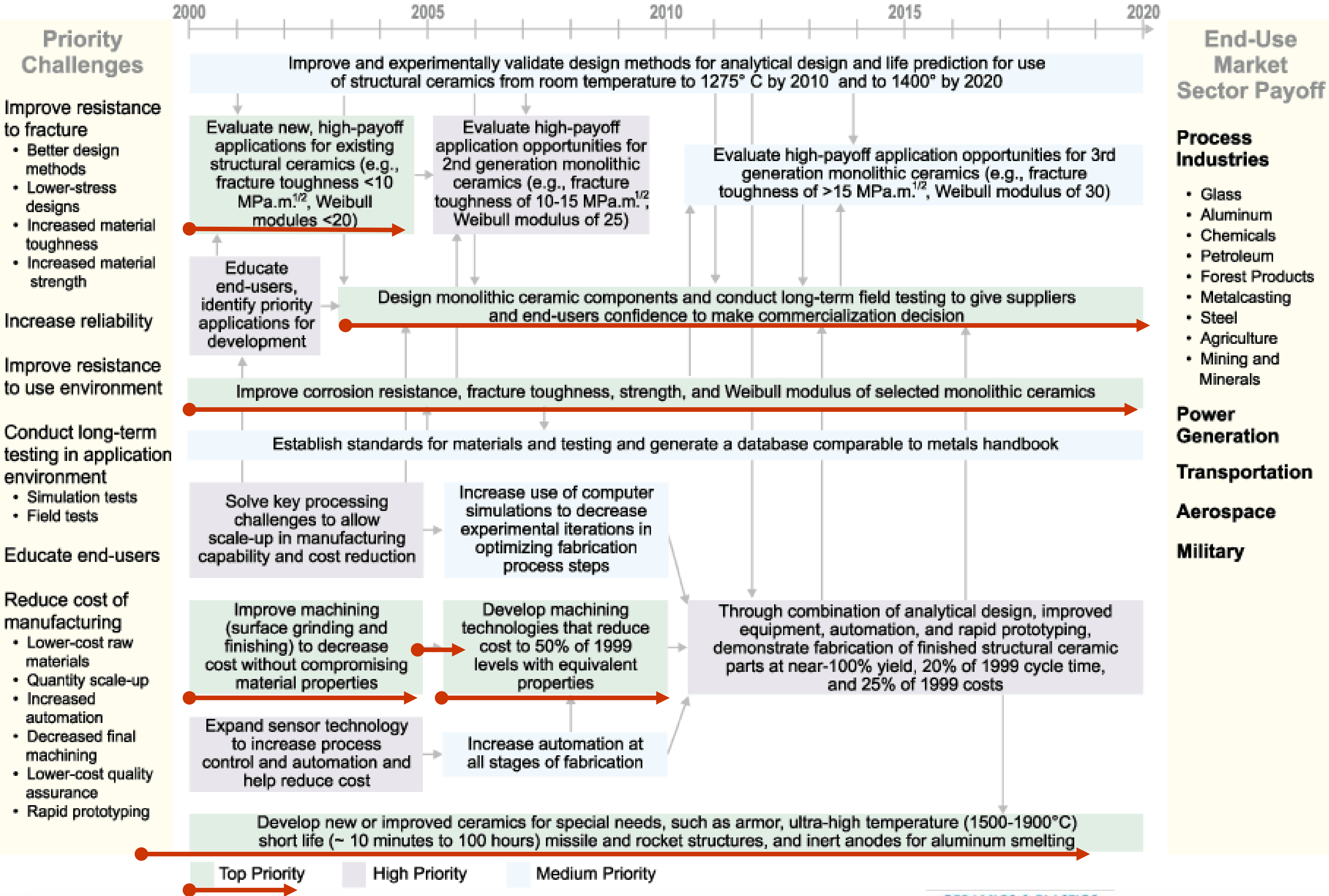
EXHIBIT 1. MONOLITHIC CERAMICS RD&D PRIORITIES

RD&D Needed to Meet End-User Requirements



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AC Roadmap - Summary of R&D Priorities

Monolithics

> Evaluate high payoff applications -- Long-term field testing
> Develop materials for new applications
> Improved corrosion resistance and fracture toughness
> Reduce manufacturing cost, especially dense machining

CMC

> Improved understanding of CMC constituents
> Improved fibers and EBC for high temp life (1200-1500 C)
> Evaluate high payoff applications
> Reduce cost, especially fibers and interface coatings

Coating Systems

> Improved adhesion understanding, failure mode understanding
> Improved EBC performance for SiC and Si3N4
> Reduced cost -- Faster coating, Intelligent processes

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Summary and Conclusions

Advanced Ceramics

> Monolithics, CMC and Coatings

Enabling Material - Where metals melt

> Temp/Environment resistant, low weight, high mod……

Wide range of cost-performance options within each group

> Compostion

> Process - Surface and Bulk Properties

> Mictrostructure

Current Uses in Industries of the Future

Opportunities for IoF and Process Heating

> Existing and new technology

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